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Study of Isodamage Prediction for Enhanced Payloads

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Isodamage curves give information concerning the failure of structures, machines and other elements. The ordinate and abcissa of the isodamage curve are associated with the physical parameters of the failure mechanism. The curve itself is a constant energy curve which predicts degrees of damage as a function of the physical parameters. At least one experimental point is necessary to construct the isodamage curve. Using this one point, the entire isodamage curve can be constructed along with the curve which will result in more damage and those for less damage.

In this study methods for obtaining isodamage curves for equipment located in command and control facilities, and biological and chemical facilities, in support of the Enhanced Payloads Program at DSWA will be developed..

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SUMMARY

In this study methods for obtaining isodamage curves for equipment located in command and control facilities, and biological and chemical production facilities, in support of the Enhanced Payloads Program at DNA will be developed.

SECTION 1

INTRODUCTION

1.1 BACKGROUND.

The Enhanced Payloads Program at DNA is exploring non-nuclear technologies to support defeat of hard targets for which high explosive weapons are ineffective. The original effort on this contract was to support thermal warhead technology concepts. The broader aspects of contamination damage have become a primary concern. The present objectives of the Enhanced Payloads Program concern two areas:

1. Thermal and contaminants against electronic equipment in CW production facilities.

2. Thermal, combustion, contaminants and small fragments against CBW agents and their production equipment.

The aim of this study is to support these two areas by developing isodamage prediction capability. This report focuses on the development of the isodamage analysis including synergistic effects. The damage mechanisms to be treated are blast, fragments, thermal and contaminants.

1.2 DESCRIPTION AND VALUE OF ISODAMAGE CURVES.

Isodamage curves trace the damage as a function of the parameters involved in the damage. For example, at a test run, a certain level of damage occurred when the temperature reached T1 degrees at t1 seconds after heating was started. This one point is plotted on a curve of temperature as a function of time. From this one point and from general physical laws governing the damage process, we can predict other combinations of time and temperature which will result in this same damage. We can also predict the parametombinations which will result in more damage and those which will result in less damage.

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The curves drawn in the temperature - time plane describing
this phenomenon are called thermal isodamage curves. Using
these thermal curves the capability of a weapon to destroy a
given target can be predicted. The thermal isodamage curves
can be developed experimentally by performing a series of
tests with various times and temperatures, and observing the
damage levels corresponding to these points. Extensive blast
tests of this nature were done at Aberdeen Proving Ground in
the 1940's and 1950's to develop aircraft isodamage curves
for blast. (Ref. 3)

The curves can also be developed through analysis by using
only one test value, and the general physical law
associated with the mechanism of damage. The latter method
is used in this report.

SECTION 2
DESCRIPTION OF DAMAGE MECHANISMS

2.1   BLAST.

Blast does damage by engulfing a structure and deforming or breaking it apart through intense pressure loading. The time element is taken into consideration by determining the impulse. Pressure and impulse are the parameters used in determining the damage from blast loading. The blast pressure and impulse produce large dynamic stresses which are sufficient to plastically deform and/or break up the target.

2.2   FRAGMENTS.

Fragments do damage by penetrating and perforating a target. Blast envelops a target. Fragments locally pierce the structure. Both load the target mechanically, but fragments do the damage by local perforation and shearing stresses while blast envelops the entire target producing tensile and compressive stresses.

2.3   HEAT (THERMAL DAMAGE).

Equipment will not operate properly when the temperature becomes excessive. Thus, heating an environment to high enough temperatures is one way to destroy a target. Heating the air in the environment surrounding a piece of equipment can even produce enough thermal energy to disable the equipment without destroying it.

The heated air reaches the target by convection. The convected heat energy converts into conductive heat energy which is diffused into the target.

2.4 CONTAMINATION.

Contamination of equipment is due to adsorption of vapors and fumes on the surface of the equipment from gases generated by the weapon (Ref. 6). Adsorption is defined as the attraction of vapors or, in their condensed form, liquids, to a surface, and the retention of vapors by a surface. Adsorption can be accompanied by absorption and diffusion through the surface.

There are two types of adsorption -- physical and chemical. When the adsorption takes place through forces of physical attraction, it is called physical adsorption and is similar in nature to the condensation of vapor on the surface of its own liquid. When the adsorption tends to form chemical bonds the process is called chemisorption. Whether or not both types of adsorption occur will depend upon the characteristics of the surface and gases, and on the pressures and temperatures.

SECTION 3

ISODAMAGE PREDICTION

3.1 GENERAL APPROACH

It has been found in many cases where blast and fragments were involved in the damage that the energy imparted through these mechanisms was a measure of the damage. It is therefore assumed that the energy associated with each mechanism is a measure of the damage that the mechanism does to the structure or equipment.

In situations involving more than one mechanism, i. e. synergistic effects, it is assumed that the total energy flux imparted to the equipment or structure is a measure of the damage for a given set of parameters. For other sets of parameters, the implications of the energy theory are -- if more energy is directed toward the target, more damage will be inflicted. If less energy is directed toward the target, less damage occurs.

It is important to note that the energy directed toward the target is the primary focus, and it is that energy which initiates the damage. This concept is important in describing contamination damage since the energy directed toward the target will usually be in the form of physical adsorption.

In many cases, after physical adsorption occurs, chemisorption (chemical reactions), absorption, and diffusion into the target can occur. At low temperatures chemisorption may be so slow that for practical purposes only physical adsorption is observed. At high temperatures physical adsorption is small (because of low adsorption energy) and only chemisorption occurs (Ref. 11). Whether or not both types of adsorption occur depends upon the characteristics of the surface, the pressures and temperatures.

The weapon contains a given amount of energy in different forms, which it projects toward the target. The target will extract the energy to which it is most vulnerable. The remaining part of the energy will be dissipated. The weapons being studied here are those which contain considerable amounts of thermal energy, (sufficient for combustion) small fragment energy and chemical content which will cause adsorption by the target so that contamination takes place.

3.2 BLAST DAMAGE

Extensive blast tests conducted at Aberdeen Proving Ground in the 1940's and 1950's (see Ref.2,3) indicate that the most convenient way to describe blast damage is by using a P - I (pressure-impulse) curve as shown below.
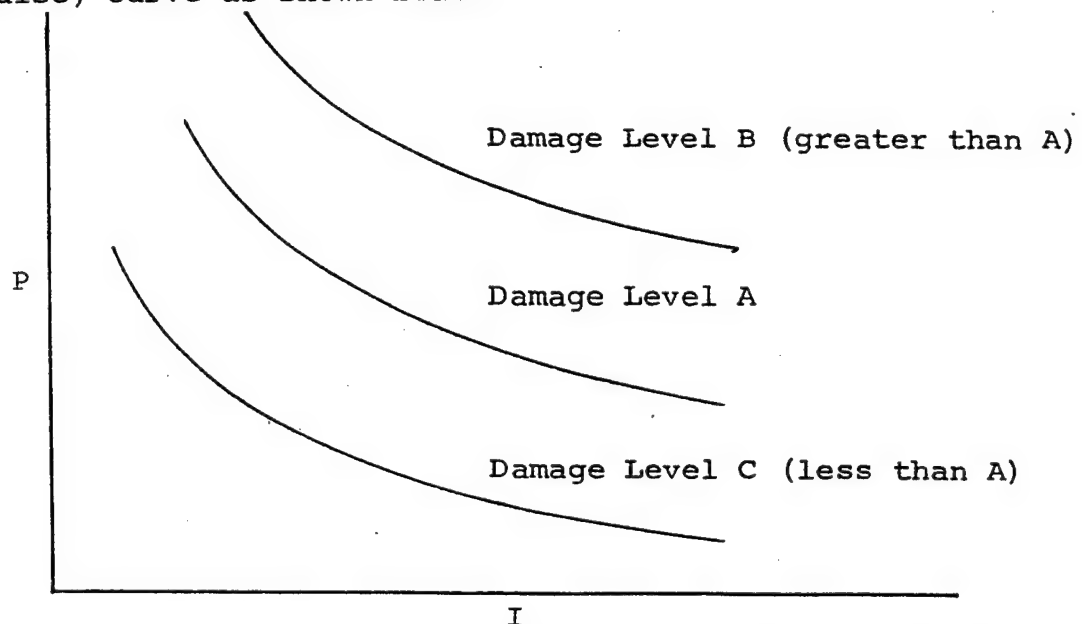
It was later discovered (Ref. 1) that the damage curves in the P - I plane were approximated by constant energy curves. Thus the energy directed toward the structure is a measure of the damage inflicted. If blast alone is involved and if values of P and I are determined from tests which give a certain level of damage, then the energy flux, describing the energy per unit area projected from the blast onto the structure is given by

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$$(E_f)_{blast} = \frac{P\,I}{2\,\rho_0\,C_0} \qquad (3.1)$$

where

ρ_0 = air density

C_0 = sound velocity in air

The energy theory states that any combination of P and I which give this same value of   will result in the same damage.

3.3 FRAGMENT DAMAGE.

Extensive tests were carried out at the New Mexico Institute of Technology (Ref. 4) in the 1960's and 1970's. The tests involved focused fragments on portions of aircraft, and it was found that the best way to describe fragment damage was by use of a v - M (velocity of fragment vs mass of fragment) curve. They found that the damage curve in the v - M plane was also a constant energy curve. The fragment energy flux can be written

$$(E_f)_{fragments} = \frac{\left[\frac{1}{2} \sum_{i=1}^{N} M_i\, v_i^2 \right]}{A} \qquad (3.2)$$

where   is the velocity of the ith fragment,
is its mass and   is the area over which the damage takes place, N is the number of fragments. If only fragment damage is involved then the above equation states that if the mass and velocity of fragments is determined for a given level of damage, then we can determine any other combination of mass and velocity

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which will result in the same level of damage.

3.4 THERMAL DAMAGE.

It is assumed that the heat is transferred from the weapon to the
structure or equipment by convection. The total convected energy
is given by Q. If the temperature increases linearly with time
during the damage process, the thermal damage is described by the
following equation:

$$\frac{2\,Q}{h\,A} \Big/ t \;=\; T \tag{3.3}$$

where

  Q = total heat added to the structure or   equipment
  (thermal energy)
  h = convection coefficient
  t = time
  T = temperature increase above ambient
  A = area over which the damage takes place

The thermal energy flux (energy per unit area) is given by

$$(E_f)_{thermal} \;=\; T\,t\,h/\,2 \tag{3.4}$$

If the temperature and time at which a given level of thermal
damage occurs is known, then other temperatures and times can be
determined which give this level of damage. Combinations of times
and temperatures resulting in more thermal energy flux result in
more thermal damage. Combinations giving less energy flux result
in less thermal damage.

3.5 CONTAMINATION.

The following phenomena have been established regarding contamination damage:

1. Contamination failures are the most common mechanisms for failure of integrated circuits in ordinary operating circumstances (Ref. 5).

2. Contaminant retention is by surface energy effects and/or chemical attraction forces and is due to solid deposits and adsorption of vapors and fumes (Ref. 6).

3. Explosions in confined spaces lead to extensive production of vapors and fumes. Thus adsorption is a major component of contamination in such cases.

In Section 2.4 the two kinds of adsorption, physical adsorption and chemisorption, were discussed. The chemical adsorption process, of necessity, first involves a physical adsorption process as the molecule approaches the surface, because of the larger range of the physical forces.

The transition from physical to chemical adsorption may be associated with an activation energy (Ref. 7). This activation energy would be supplied by thermal sources involved in the damage process.

It is sufficient to determine approximate relations for the energy associated with physical adsorption. Other phenomena such as chemisorption, absorption and diffusion will follow.

Brunauer (Ref. 8) gives relations for the adsorption potential (which is the energy associated with physical adsorption). The three regions of adsorption are as follows:

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1. Far below critical temperature so that Practically all adsorbed gas is in liquid form.
2. Below but near critical temperature where there is liquid and compressed gas in the adsorption space.
3. Above critical temperature where there is only compressed gas in the adsorption space.

The critical temperature is about 1.5 times the boiling point on the absolute temperature scale. For regimes 1 and 2 the energy, E, can be approximated by the following relation:

$$E_{contamination} = R\ T\ LN\ (p_0/p_x) \qquad (3.5)$$

where

p_x = pressure existing in the gas phase
p_0 = vapor pressure of the liquid
R = Boltzmann's constant
T = absolute temperature

For region 3 above the critical temperature

$$E_{contamination} = R\ T\ \left[\frac{V_i}{V_i - b} - \frac{V_x}{V_x - b} \right] \quad [6]$$

$$+ R\ T\ LN\ \left[\frac{V_x - b}{V_i - b} \right] + 2\ a\ \left[\frac{1}{V_x} - \frac{1}{V_i} \right] (3.6)$$

$$V_i = M/\delta_i \qquad V_x = \frac{R\ T}{P_x}$$

where

a, b = Van der Waal's constants of the gas
P_x = pressure
T = absolute temperature
M = molecular weight of the gas
δ_i = density of the gas at temperature T

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3.6 SYNERGISTIC EFFECTS.

In a combined process which involves blast, thermal, fragments and contamination the energies are added as follows:

$$(E_f)_{Total} = (E_f)_{Blast} + (E_f)_{Fragments} + (E_f)_{Thermal} + \frac{(E)_{Contaminants}}{A} \quad (3.7)$$

This Synergistic equation given above predicts that in any destruction process, if one set of values can be determined for P, I, M , v_i , A, T, t, and the appropriate parameters in the contamination energy which result in damage, then the total energy resulting in this damage can be computed.

Any other set of values which results in this same energy flux results in the same damage. If the total energy flux with a new set of values is less, there will be less damage. If the energy flux is greater, the damage will be greater.

SECTION 4

THERMAL ISODAMAGE CURVES FOR SPECIFIC CASES

Thermal Isodamage Curves were developed using data from IDR Progress Reports (Ref. 9). Figure 1 shows the predicted thermal isodamage curve for an electric motor with a 1" steel case. Lubricant breakdown caused the failure when the external temperature reached 500 deg. C at 120 seconds. The solid curve represents the convection theory as developed in the previous sections of this report.

The experimental points for two other times and temperatures are shown on the curve. It is seen that the theory predicts reasonable results. Figure 2 shows the predicted thermal isodamage curve for a circuit board based on the failure criteria of 280 deg. C and 10 minutes (600 seconds). The results at this temperature and time were (Ref. 9)

1. Solder melts and chips separate
2. Board chars/pyrolyzes
3. Solder mask pyrolyzes
4. Connector distorts

Figure 3 shows the predicted curve for a computer based on a temperature of 350 deg. C and a time of 5 minutes (300 seconds). The test showed a kill for that exposure.

Finally, Fig. 4 shows a series of thermal isodamage curves for a water chiller unit. The points used for the calculatiion corresponding to various degrees of damage are shown in the figure. The description of the damage is given at the bottom of the figure.

Recently a test was conducted by SAIC on a programmable logic controller with a combination of hydrochloric acid and heat (Ref. 10). It was not determined whether the synergistic effect of the combination or just the heat alone caused the failure.

The HCL alone did not cause the failure. In such cases it would be valuable to determine the amount of HCL without heat which produces failure, as opposed to the amount of heat without HCL. A synergistic isodamage curve could be constructed using these two pieces of information.

SECTION 5

RECOMMENDATIONS AND PLAN FOR IMMEDIATE FUTURE

5.1 RECOMMENDATIONS.

It is recommended that any of the tests performed with
synergistic effects such as thermal and contaminants be carried
out in three stages. First determine degrees of damage under the
contaminant alone, then thermal alone and finally under the
combination.

Thermal, combustion, contaminants and small fragments tests
should be conducted in five stages. First use each damage
mechanism and then combinations.

The isodamage theory can then be tested with experimental data
from the program. Part IV of the report showed Thermal Isodamage
Curves developed from actual data. Prediction of isodamage curves
from other mechanisms will follow similar proecdures.

5.2 PLAN
5.2.1 General Approach.
The contractor will further develop the synergistic theory
so that the tests on combinations can be reduced to a
minimum by using the results of the damage from individual
mechanisms. The final result will predict damage using any
combinations of the individual mechanisms. This will result
in considerable savings of time and effort in the program.
It will also result in a better understanding of how the
damage takes place under synergistic effects.

5.2.2 Development of criteria not based on energy alone.

This report was devoted to development of isodamage curves
based on energy criteria. Other possibilities exist which

the contractor expects to explore. In the case of
contamination via adsorption, not just the energy, but the
amount adsorbed, which is he subject of most of the
adsorption computations at the present time, may be a key
factor in determining the degree of damage. How this couples
with other mechanisms will be examined.

Energy has the big advantage of being able to couple
together the synergistic effects since the energy involved
in each destruction mechanism can be added together. If
other factors are more important than energy, the the proper
coupling parameters must also be found in order to study
synergistic effects.

SECTION 6

REFERENCES

1. Greenspon, Joshua E. "Some Basic Principles for Damage to Structures by Fragments and Blast", J G Eng. Res. Assoc., Contract DAAD05-72-C-0195, BRL Contract Rep. No. 96, March 1973.

2. Sperrazza, Joseph "Modelling of Air Blast" contained in "Use of Models and Scaling in Shock and Vibration", Winter Meeting of ASME, Nov. 1963, Edited by W. E. Baker, p. 65.

3. Sperrazza, Joseph "Dependence of External Blast Damage to A-25 Aircraft on Peak Pressure and Impulse (U)", BRL Memo. Rep. No. 575, Sept. 1951, AD#378275.

4. "New Mexico Institute of Mining and Technology Methodologies", contained in "Compendium of Methodologies for Assessing Aircraft Structural Damage from Multiple Fragment Impacts", JTCG/ME Rep. 61JTCG/ME-76-16, 11 Jan. 1977.

5. Lee, T. W. and Pabbisetty, S. V. eds. "Microelectronic Failure Analysis," ASM International, Materials Park, OH, 1993, p.277.

6. Tautscher, C. J. "Contamination Effects on Electronic Products", Marcel Dekker, Inc., NY, 1991, p.9.

7. Jaycock, M. J. and Parfitt, G. D. "Chemistry at Interfaces", John Wiley & Sons, NY, 1986, p. 164.

8. Brunauer, Stephen, "The Adsorption of Gases and Vapors, Vol. I Physical Adsorption", Princeton University Press, 1943.

9. IDR (International Development and Resources, Inc.) Progress Reports of 3/9/95 and 4/6/95 on Contract DNA 001-94-C-0194.

10. Private Communication from Dr. K. Kim.

11. Adamson, A. W., "Physical Chemistry of Surfaces," John Wiley nd Sons, 1976, 3rd Edition, p. 550.
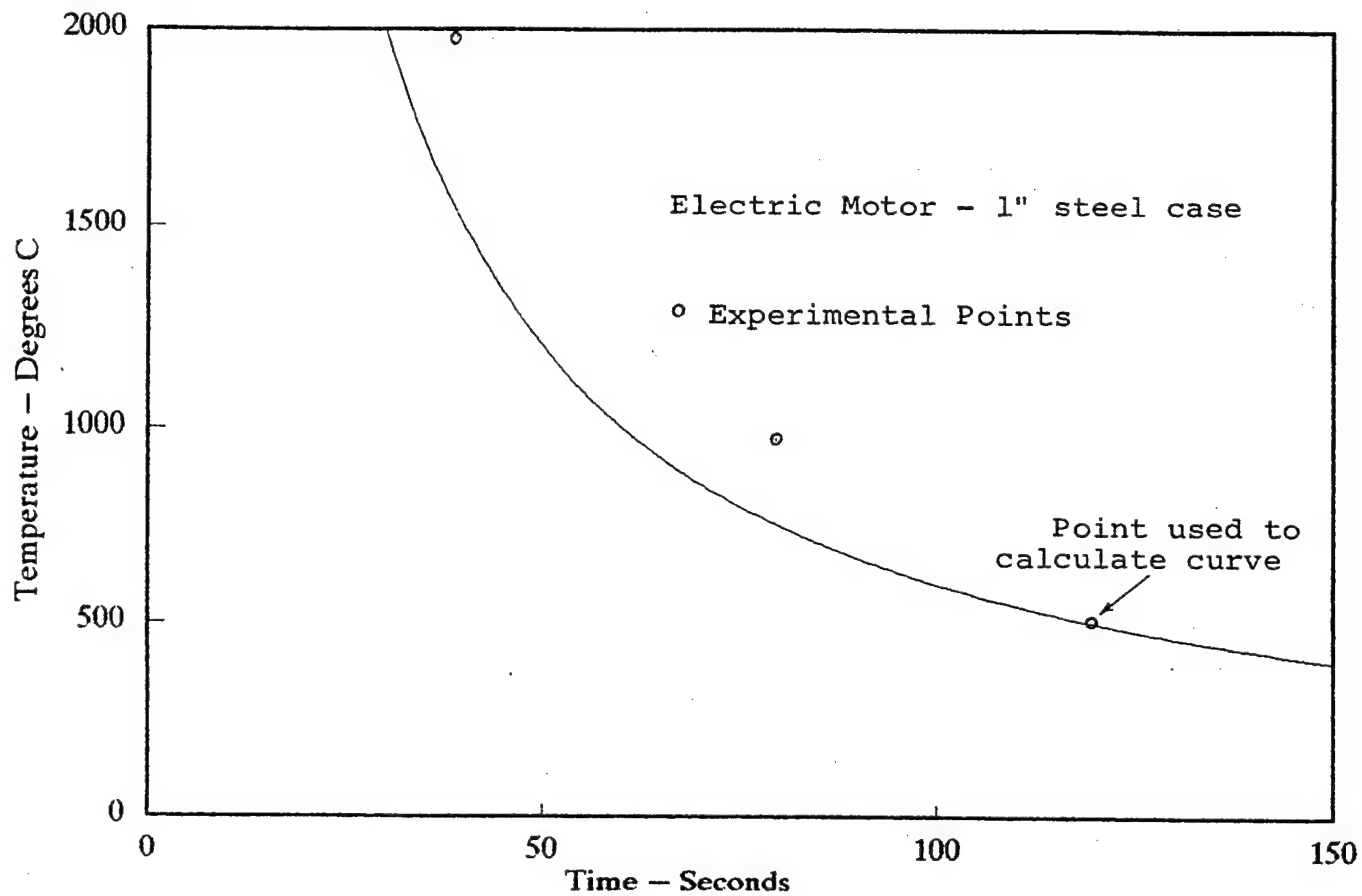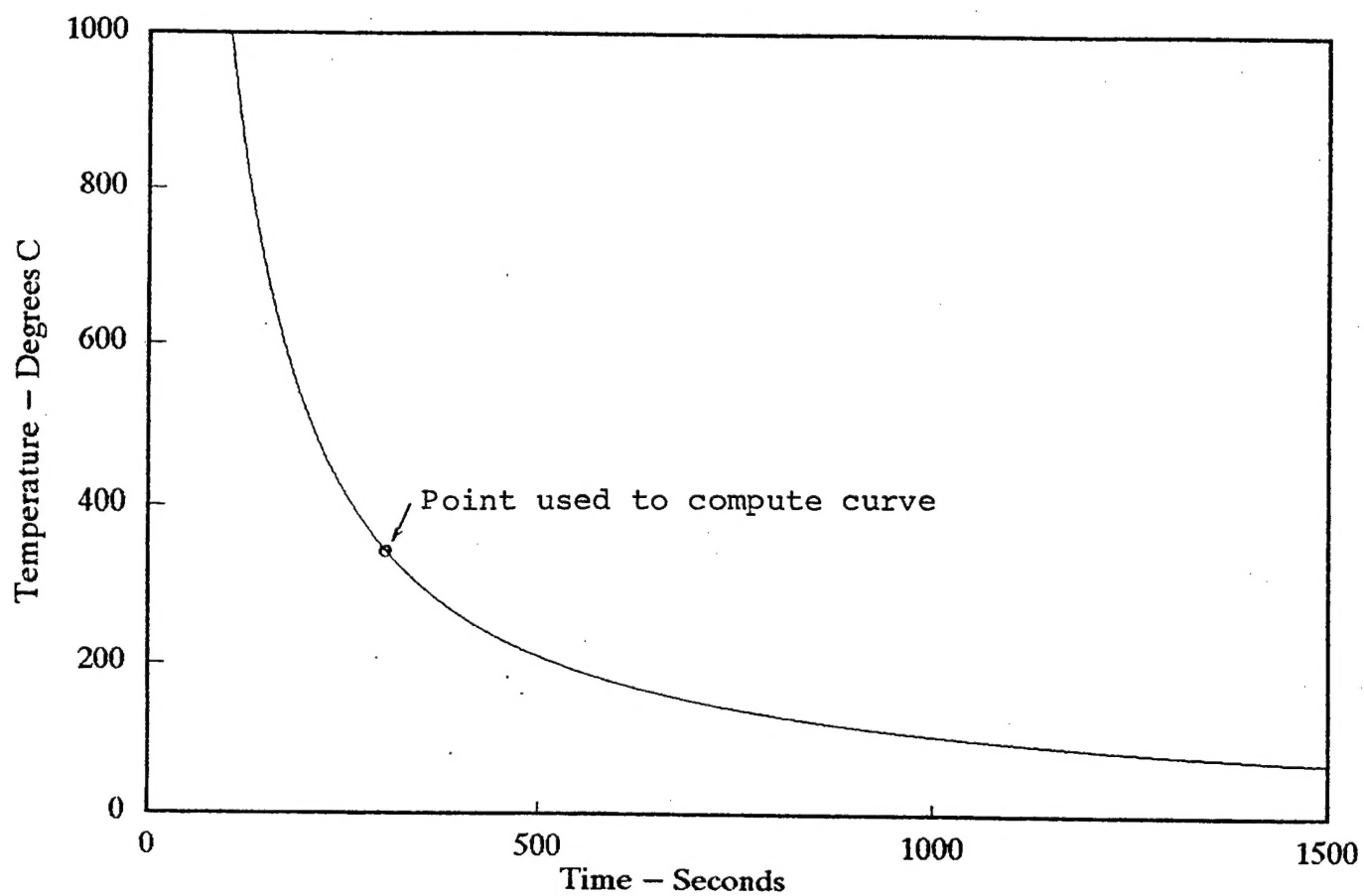
a. Electric Motors and Pumps
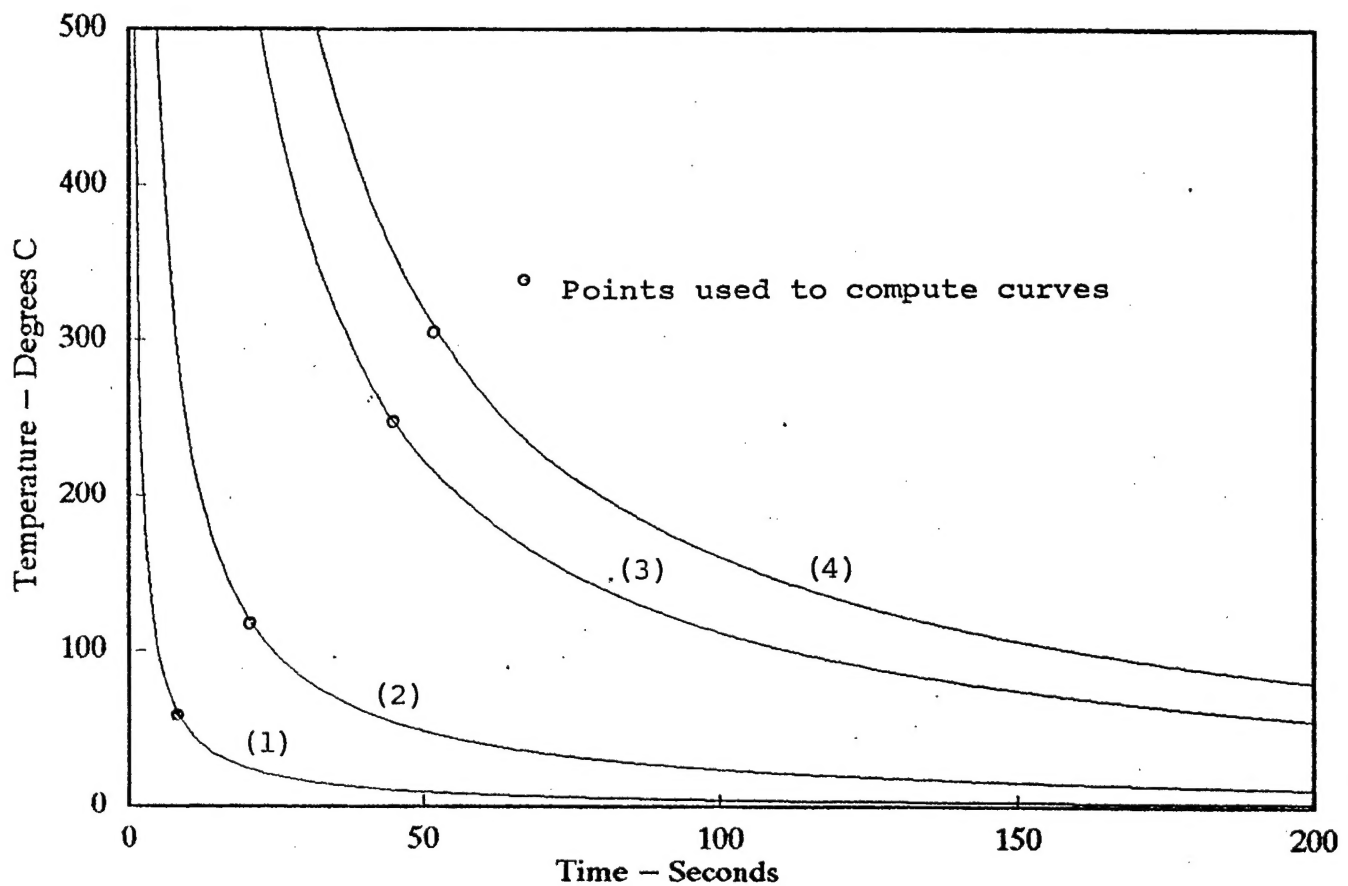
Figure 4-1. Thermal isodamage curve.
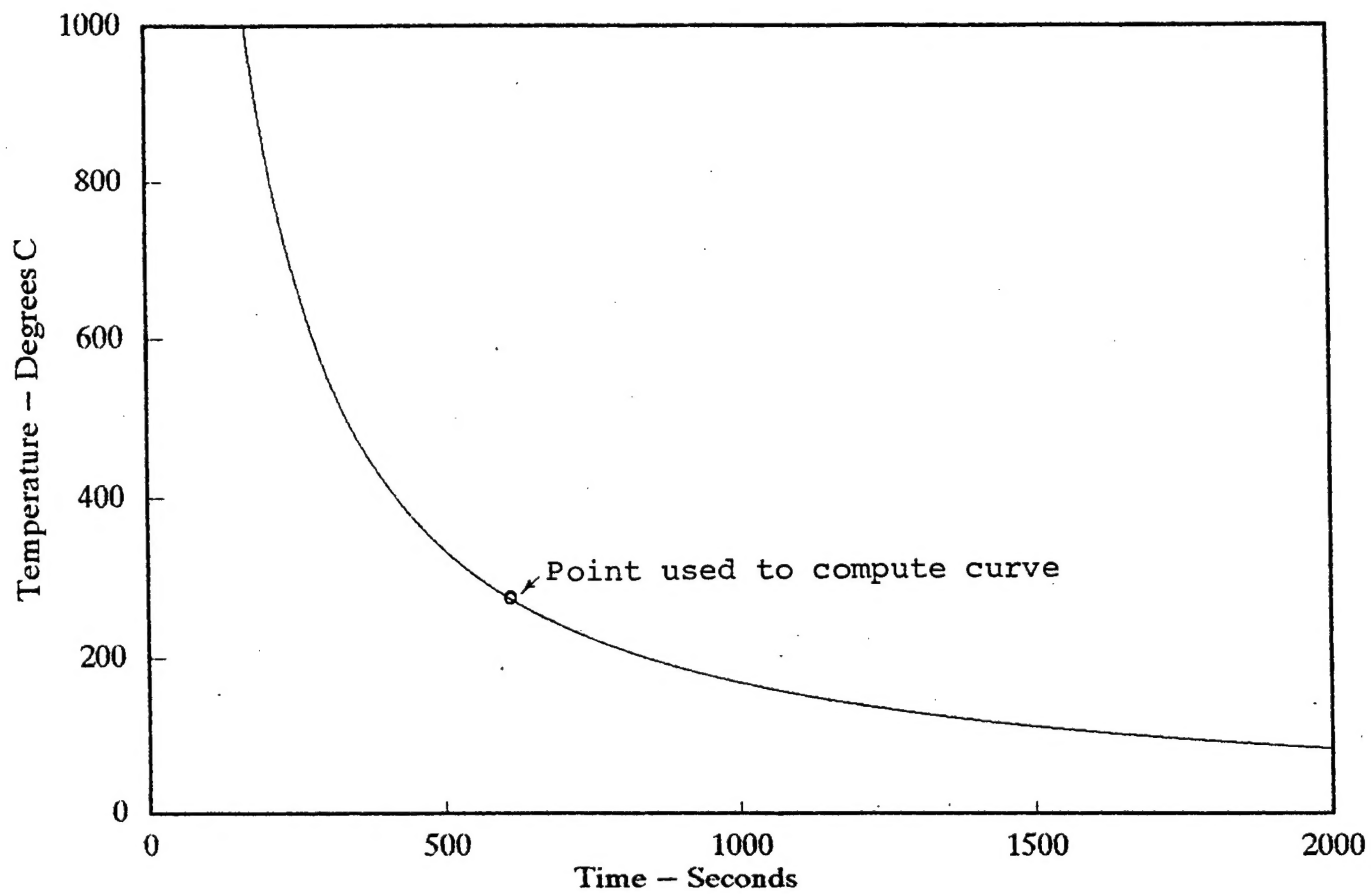
b. Circuit Board

Figure 4-1. Thermal isodamage curve (Continued).

Figure 4-1. Thermal isodamage curve (Continued).

c. Computer

d. Water Chiller Unit

(1) Auto shutoff at about 55 deg. C; no physical damage
restart after cooldown

(2) Compressor blows coolant charge at about 60 deg. C;must
replace valve

(3) Microprocessor destroyed at about 280 deg. C; requires
replacement

(4) Motor burnout; meltdown of plastic spacer rings for bearings
at about 320 deg. C

Figure 4-1. Thermal isodamage curve (Continued).

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